TECHNICAL MEMORANDUM

July 18, 2014

TO: Robin Kirschbaum, P.E., HDR Engineering Inc.

FROM: Bruce Barker, P.E., MGS Engineering Consultants, Inc.

SUBJECT: Assessment of current runoff rates and retrofits needed to meet specified targets in the Miller and Walker Creek Watersheds

BACKGROUND

The hydrology of the Miller and Walker Creek watersheds has been extensively analyzed as part King County's Miller and Walker Creeks Basin Plan (King County DNR, 2006), the Port of Seattle's Airport Expansion Project (Parametrix, Inc., 2001) and studies to analyze the bedload movement characteristics and to develop habitat improvement structures in the lower reaches of Miller and Walker Creeks (MGS Engineering Consultants, 2008, 2009, 2013). The analysis discussed in this memorandum utilized the latest Hydrologic Simulation Program -Fortran (HSPF) hydrologic model developed as part of these analyses.

The purpose of this analysis is to provide information on the spatial distribution of runoff rates, Benthic Index of Biotic Integrity (B-IBI) estimates based on simulated runoff statistics, and the amount of stormwater retrofits needed to improve streamflows and aquatic conditions in the basin. This information will be used by engineers and other technical specialists working on King County Water and Land Resources Division's (WLRD's) Miller and Walker Creek Basin Stormwater Retrofit Planning Study to help target recommendations for siting retrofit facilities. Details on the HSPF model setup and calibration can be found in the reports *Hydrologic Analysis of Miller and Walker Creek Watersheds to Identify Watershed-Specific Stormwater Treatment Standards* and *Hydrologic and BIBI Analysis of the Miller and Walker Creek Watersheds* (MGS Engineering Consultants, 2013).

The target flow regime for the Miller and Walker Creek watersheds is intended to mimic the hydrologic response under forested conditions to the greatest extent feasible. Specifically, this entails including Low Impact Development (LID) and traditional stormwater detention that controls the post-developed flow duration between 8-percent of the 2-year and the 50-year recurrence interval to predeveloped (forested) conditions.

SPATIAL DISTRIBUTION OF RUNOFF RATES THROUGHOUT THE WATERSHEDS

The HSPF model was used to develop flood-frequency statistics throughout the watershed. Precipitation from the Sea-Tac gage and daily evaporation derived from the Puyallup 2 West Experimental Station (station number 45-6803) for the period of 1948-2011 were used as input to the model to compute a 63-year time series of flow at a 1-hour time step at the outlet of each subbasin.

Peak discharge flood-frequency results at the outlet of each subbasin for the 2-year recurrence interval expressed as cfs/tributary acres are shown in Figure 1. There are a large number of hydrologic statistics that could be used to quantify the hydrologic response from the watershed. However, the 2-year discharge was chosen because it provides a simple index of the relative flood response from each subbasin and is close to discharges usually associated with streambed movement and stream channel stability.

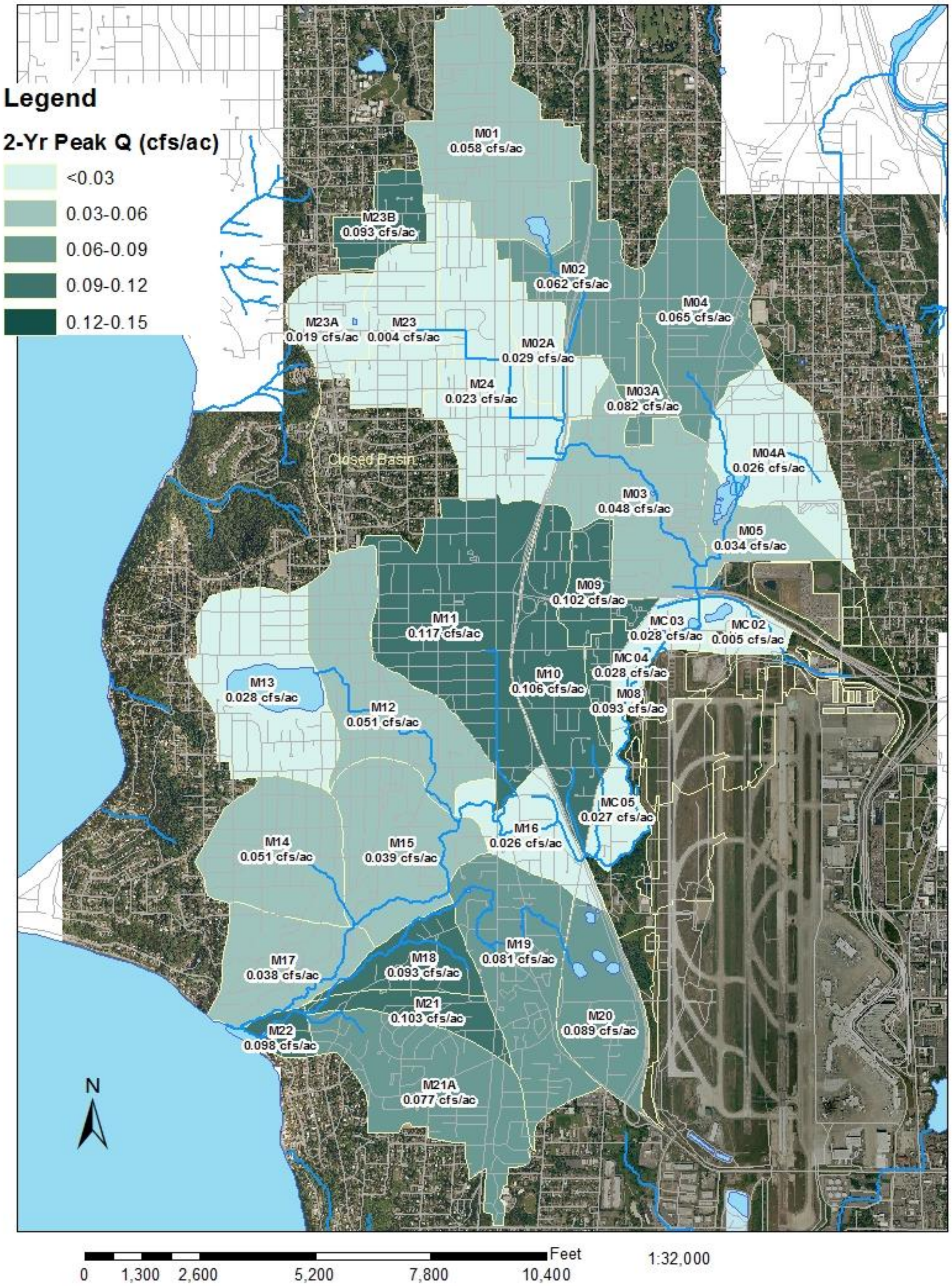

Figure 1 – 2-Year Peak Discharge Rate at the Outlet of Each Subbasin Simulated with HSPF Expressed as cfs/tributary acres (Existing Land Use)

Figure 1 shows high rates of runoff from commercial development along First Avenue South and State Route (SR)-509 in the City of Burien (Subbasins M09, M10, and M11). The land use density in Subbasin M11 is the highest in the watershed. A regional detention facility (Ambaum Way Detention Pond) at the subbasin outlet reduces the peak discharge somewhat but is nowhere near large enough to fully mitigate discharges to historic conditions. Runoff rates in the stream along the west side of Sea-Tac airport are relatively small because of detention storage (Miller Creek Regional Detention Pond), wetlands along the stream, and the presence of stormwater controls at the airport.

Discharges from Walker Creek benefit from the presence of wetlands in the central portion of the watershed (Subbasin M20) and the Sea-Tac airport detention facilities. Subbasins downstream of Des Moines Memorial Drive had relatively high runoff rates because of high channel gradients and a lack of stormwater controls. There is little in the way of stormwater controls in most residential areas in the Miller and Walker Creek watersheds and without the benefit of regional detention or natural lakes or wetland buffering, the runoff from these areas adds considerably to the total peak discharge rates.

ESTIMATES OF B-IBI SCORES FROM SIMULATED HYDROLOIGC STATISTICS

The Benthic Index of Biotic Integrity (B-IBI) was developed as an index to quantify the ecological condition of streams in the Pacific Northwest (Kleindl, W. J., 1995, Karr el al., 1999). B-IBI scores range between 10 and 50, with higher scores representing more pristine conditions. B-IBI scores have been assigned qualitative descriptions of stream condition by Karr el al., 1999 (Table 1).

Table 1 – Qualitative Categorization of B-IBI (Karr et al. 1986)

Condition	Description	B-IBI Range
Excellent	Comparable to least disturbed reference condition; overall high taxa diversity, particularly of mayflies, stoneflies, caddis flies, long-lived, clinger, and intolerant taxa. Relative abundance of predators high.	46-50
Good	Slightly divergent from least disturbed condition; absence of some long-lived and intolerant taxa; slight decline in richness of mayflies, stoneflies, and caddis flies; proportion of tolerant taxa increases.	38-45
Fair	Total taxa richness reduced – particularly intolerant, long-lived, stonefly, and clinger taxa; relative abundance of predators declines; proportion of tolerant taxa continues to increase.	28-37
Poor	Overall taxa diversity depressed; proportion of predators greatly reduced as is long-lived taxa richness; few stoneflies or intolerant taxa present; dominance by three most abundant taxa often very high.	18-27
Very Poor	Overall taxa diversity very low and dominated by a few highly tolerant taxa; mayfly, stonefly, caddis fly, clinger, long-lived, and intolerant taxa largely absent; relative abundance of predators very low.	10-17

B-IBI scores have been related to several hydrologic metrics that quantify the impacts to streamflow from urbanization by DeGasperi et al. (2009) and Horner (2014). The Horner equations utilized the same dataset used by DeGasperi and developed regression equations relating B-IBI to the hydrologic metrics High Pulse Count (HPC) and High Pulse Range (HPR) including 90-percent confidence bounds. The Horner equations summarized in Table 2 were used to estimate B-IBI values using HPC and HPR values computed with the HSPF model for existing conditions in the Miller and Walker Creek watersheds. B-IBI values obtained from the HPC and HPR regression equations in Table 2 were averaged to obtain the final B-IBI values at the outlet of each subbasin. The results are presented in Figure 2 and in Appendix A.

B-IBI estimates were computed using the best estimate regression equation and the 90-percent upper confidence bound. King County has identified the 90-percent upper confidence bound to approximate the maximum potential B-IBI score if all other factors degraded by urbanization in addition to hydrology (e.g., water quality, riparian vegetation, etc.) were restored to their historic states.

Table 2 - Regression Equations and Associated Statistics Relating High Pulse Count and High Pulse Range with Benthic Index of Biotic Integrity (Reproduced from Horner, 2014)

STATISTIC			HIGH PULSE COUNT (HPC)	HIGH PULSE RANGE (HPR)
Equation			Ln (% Max. B-IBI Score) = - 0.066*HPC + 4.50[a] (Equation 1)	Ln (% Max. B-IBI Score) = - 0.005*HPR + 4.69[a] (Equation 2)
R^{2*}			0.745	0.755
Confidence limits (lower, upper)	90%	Coefficient	(-)0.084, (-)0.048	(-)0.007, (-)0.004
		Constant	4.29, 4.71	4.44, 4.95
	80%	Coefficient	(-)0.080, (-)0.052	(-)0.006, (-)0.004
		Constant	4.34, 4.66	4.50, 4.89
	60%	Coefficient	(-)0.075, (-)0.057	(-)0.006, (-)0.004
		Constant	4.39, 4.60	4.57, 4.82

[a] Ln signifies the natural logarithm.

* R^2 represents the fraction of variability in a data set explained by the statistical model. Both regressions are significant at $P < 0.001$.

Results of the analysis shows B-IBI estimates in the very poor range for the majority of the subbasins. Subbasins with higher B-IBI values are associated with higher hydrologic buffering in the form of lakes, wetlands or glacial outwash. Subbasin M23 had the highest estimated B-IBI value of 39 because of the large detention volume from Hermes Pond, which greatly reduced the high pulse count and high pulse range downstream. Estimated B-IBI values in Walker Creek were somewhat higher than Miller Creek because of the lower overall development density, wetlands located in the headwaters, and higher baseflow.

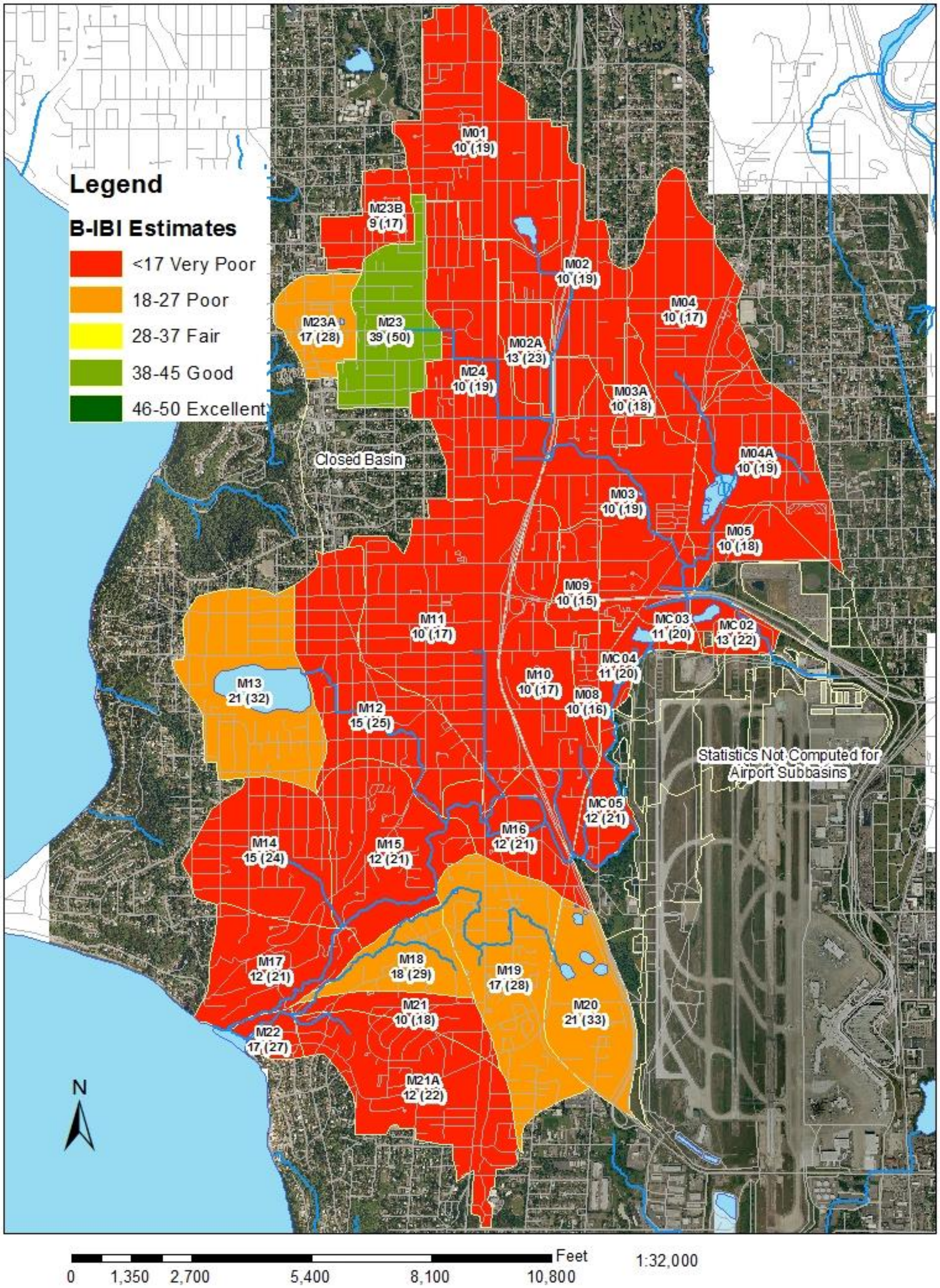

Figure 2 – Miller and Walker Creek Watersheds B-IBI Scores Estimated Using Regression Equations with Hydrologic Metrics, High Pulse Count and High Pulse Range
(Values Represent Best Estimates with Upper 90-Percent Confidence Bound shown in Parentheses)

STORMWATER RETROFIT NEEDED TO MEET THE TARGET FLOW REGIME

Much of the Miller and Walker Creek Watersheds were developed at a time when required stormwater controls were nonexistent or inadequate. As the practice of stormwater management has evolved over the past 30-years, stormwater mitigation that attempts to reduce post-developed runoff rates and flow durations to historic levels has become the standard. The target flow regime for the Miller and Walker Creek watersheds is intended to mimic the hydrologic response under forested conditions to the greatest extent feasible. Specifically, this entails including Low Impact Development (LID) and traditional stormwater detention that controls the post-developed flow duration between 8-percent of the 2-year and the 50-year recurrence interval flow rate to historic (forested) conditions.

The amount of stormwater retrofit needed to achieve the target flow control standard in each subbasin was determined using a two-step process. First, LID and detention facilities were designed for small representative 1-acre sites for land use densities of residential, and commercial/multi-family using the MGSFlood hydrologic analysis software. Second, the total LID and detention retrofit volume was determined for each subbasin by multiplying the area of each land use type in the subbasin times the facility volumes computed for the representative sites in the first step. The resulting volume for each land use type were then totaled to produce the aggregate retrofit volume needed in each subbasin.

Figure 3 shows the generalized geology map of the watersheds. Separate facilities were designed for geologic conditions of glacial till and glacial outwash. The retrofit facilities consisted of bioretention located upstream of a detention pond in areas with geology of glacial till and bioretention upstream of an infiltration pond in areas underlain by glacial outwash. The bioretention facilities were sized to control the post-developed flow duration to the forest target condition between 8-percent of the 2-year and 50-percent of the 2-year. Overflows from the bioretention facility were captured by a downstream detention/infiltration pond designed to mitigate runoff to the forest target condition between 50-percent of the 2-year and the 50-year recurrence interval. The resulting facility sizes for the 1-acre sites are summarized in Tables 3a and 3b. See Appendix B for design information used to size the retrofit facilities.

The facility sizes for the hypothetical 1-acre sites were multiplied by the actual area of each land use/geologic type in each subbasin and aggregated to determine the total retrofit volume required in each subbasin. The cumulative facility footprint area (total surface area of all facilities in each subbasin) are tabulated in Appendix C and the total volume in each subbasin (expressed as acre-feet) is shown in Figure 4 and tabulated in Appendix D. The values in Figure 4 generally reflect the development density, subbasin size, and dominant geology (till or outwash) in each subbasin. Subbasins M11 and M24 require the most retrofit storage because of the high development density relative to the other subbasins.

The required storage volume was normalized by dividing the total volume in each subbasin by the subbasin area and expressing the total volume as inches of storage over the subbasin (Figure 5). Expressing the volume as inches eliminates the influence of the subbasin size on the required volume and highlights those areas where the existing development density combined with geology suggests the greatest retrofit need.

Table 3a – Mitigation Sizes for One Acre Sites on Glacial Till

Land Use	Detention Storage Volume (ac-ft)	Detention Pond Surface Area (sf)	Bioretention Storage Volume (ac-ft)	Bioretention Surface Area (sf)
Commercial	0.296	6550	0.094	2440
Multi-Family	0.200	4370	0.077	2010
Single Family	0.138	3220	0.064	1700

Table 3b – Mitigation Sizes for One Acre Sites on Glacial Outwash

Land Use	Infiltration Pond Storage Volume (ac-ft)	Infiltration Pond Surface Area (sf)	Bioretention Storage Volume (ac-ft)	Bioretention Surface Area (sf)
Commercial	0.108	2400	0.034	900
Multi-Family	0.067	1610	0.026	740
Single Family	0.036	1010	0.017	530

Notes:

1. Storage volume is the total storage in the facility at the overflow riser crest elevation. Detention and infiltration ponds were sized to a 3-foot depth and bioretention facilities to a 1-foot depth at the overflow elevation. Bioretention facility volume includes both the ponded storage and the volume in the soil voids of the biosoil.
2. The surface area is the wetted surface area at the overflow elevation.
3. Additional information on assumed LID and detention configurations for these facilities are contained in Appendix B. The cumulative facility footprint area (total surface area of all facilities in each subbasin) are tabulated in Appendix C.

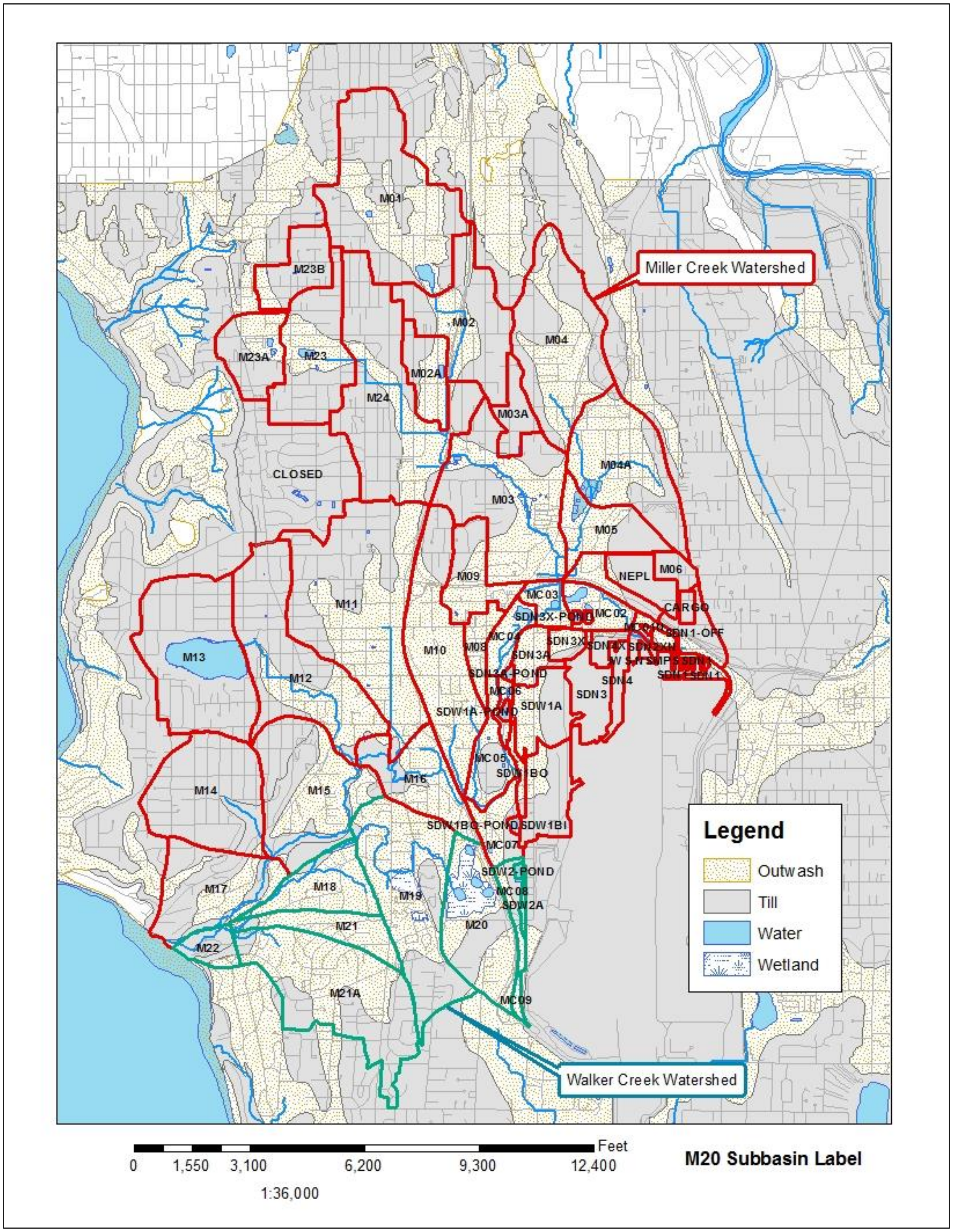

Figure 3 – Miller and Walker Creek Watersheds Geology Definitions and Subbasins used in the Hydrologic Analysis

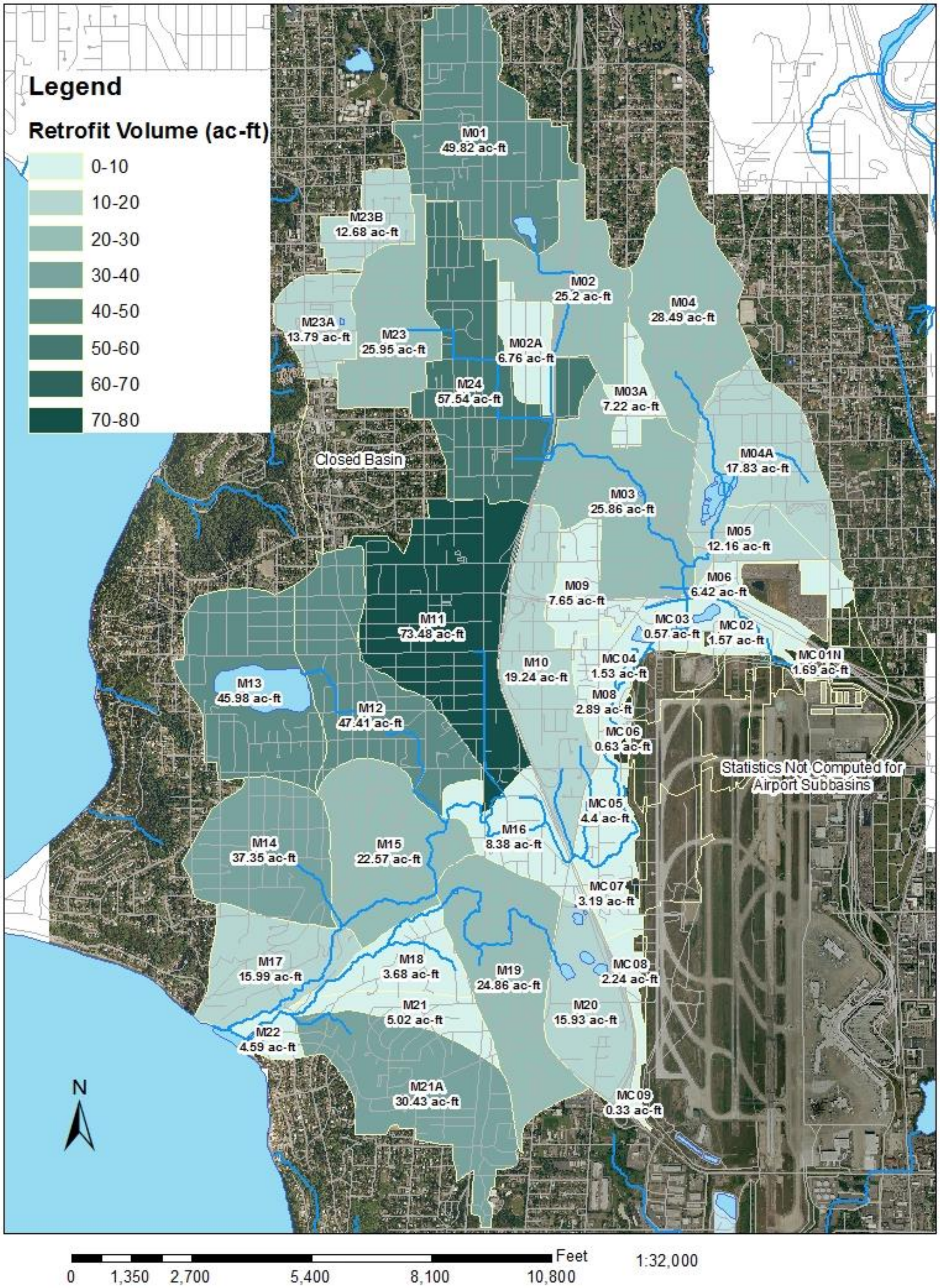

Figure 4 – Total Detention and LID Storage Volume (ac-ft) in each Model Subbasin to Retrofit Existing Land Use to Forest Conditions.

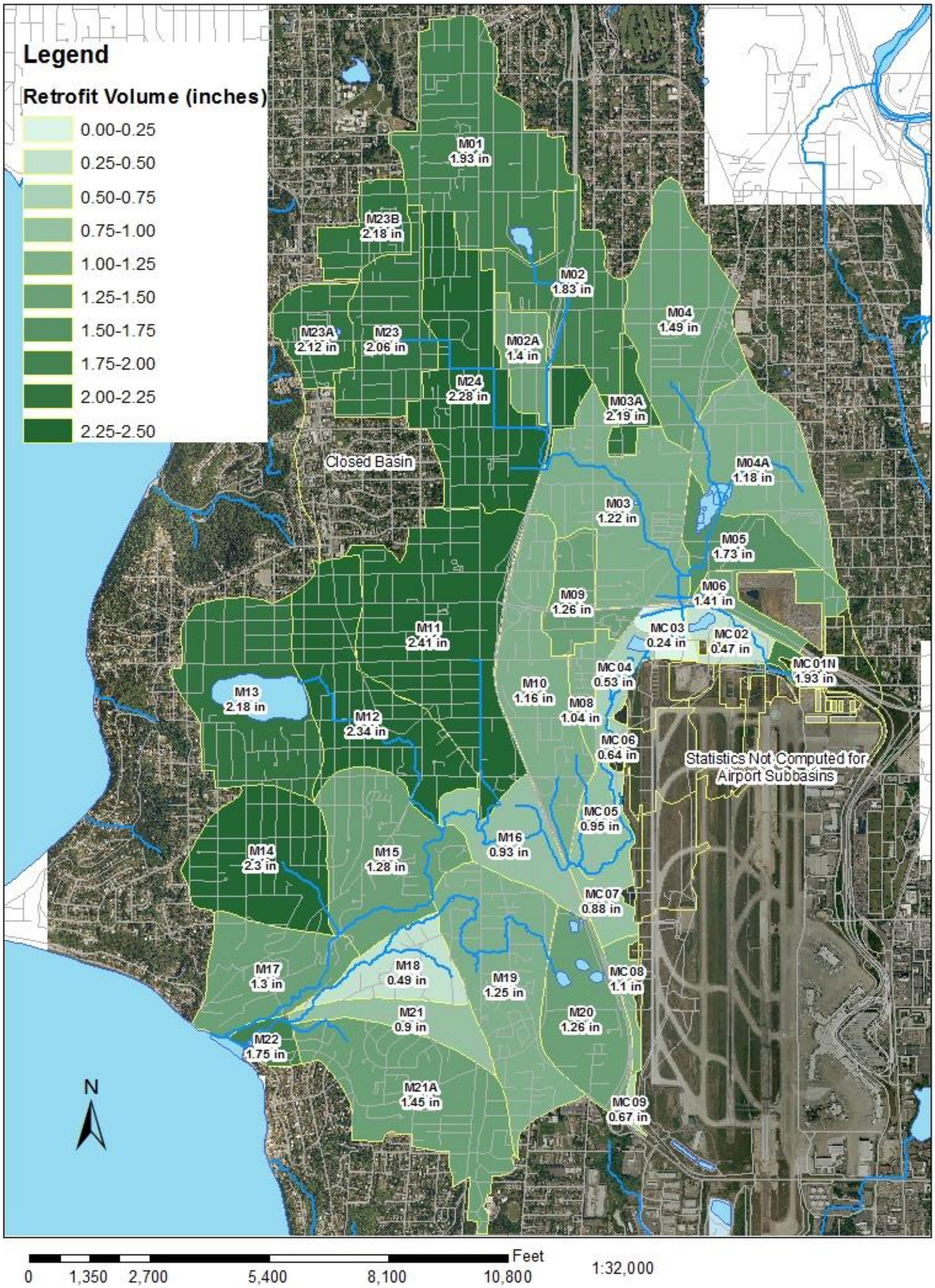

Figure 5 – Total Detention and LID Storage Volume (inches over subbasin) in each Model Subbasin to Retrofit Existing Land Use to Forest Conditions

DISCUSSION

The discharge, B-IBI estimates, and retrofit volume information presented above when viewed together provides useful guidance on focusing stormwater retrofit efforts to mitigate runoff and increase potential B-IBI scores. Subbasins that produce higher peak discharges to the streams typically have highly urban land uses, are underlain by mainly glacial till, and have little hydraulic attenuation from lakes, ponds, or wetlands. Subbasins M02, M24, M10, M11, and M12 in the Miller Creek watershed and Subbasins M21A, M18, and M19 in the Walker Creek watershed are the principal contributors to peak flow along the mainstem and would be likely candidate locations for retrofit projects.

Subbasins to target first include those with the least amount of hydraulic storage that contribute the most to high peak discharges in the streams. Retrofitting these areas first will provide the largest flow reduction benefit and would benefit coho and chum salmon, and trout spawning and rearing in the streams. These include Subbasins M10, M11, and M12 in the Miller Creek Watershed and Subbasins M18, M21, and M21A in the Walker Creek watershed. In general, the Miller Creek retrofit need is greater than Walker Creek because of the higher development densities in the Miller Creek watershed.

Locations with high infiltration potential within each of these subbasins would produce the most flow reduction and water quality improvement. These are typically in areas underlain by glacial outwash and where there is separation between the groundwater table and the ground surface. The WLRD Retrofit Study will include a separate analysis of infiltration potential, providing locations in the watershed where infiltration will be the most feasible. The general geologic map (Figure 3) can be used to provide a preliminary indication of which parts of the watersheds may be more conducive to infiltration. There are significant areas of outwash in the high runoff subbasins discussed above. These areas may provide feasible locations for siting retrofit projects depending on the proximity of the groundwater table.

APPENDIX A – B-IBI VALUES COMPUTED FOR EACH SUBBASIN, EXISITNG CONDITIONS

Regression Equations and Associated Statistics Relating High Pulse Count and High Pulse Range with Benthic Index of Biotic Integrity Used to Estimate B-IBI Scores (Reproduced from Horner, 2014)

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		Constant	4.29, 4.71	4.44, 4.95
	80%	Coefficient	(-)0.080, (-)0.052	(-)0.006, (-)0.004
		Constant	4.34, 4.66	4.50, 4.89
	60%	Coefficient	(-)0.075, (-)0.057	(-)0.006, (-)0.004
		Constant	4.39, 4.60	4.57, 4.82

[a] Ln signifies the natural logarithm.

* R^2 represents the fraction of variability in a data set explained by the statistical model. Both regressions are significant at $P < 0.001$.

Table A-1, Hydrologic Statistics and B-IBI Estimates from Horner (2014) Regression Equation (Best-Estimate)

Subbasin	High Pulse Count (HPC) (Average No High Pulses/Year)	High Pulse Range (HPR) Average High Pulse Range/Year (days)	B-IBI Regression Results (Best Estimate)		
			Regression with HPC	Regression with HPR	Average B-IBI
SUBBASIN M01	23.8	310	10.0	11.5	10.8
SUBBASIN M02	24.2	312	10.0	11.4	10.7
SUBBASIN M02A	18.5	278	13.2	13.6	13.4
SUBBASIN M03	24.5	312	10.0	11.5	10.7
SUBBASIN M03A	25.9	326	10.0	10.7	10.3
SUBBASIN M04	28.0	331	10.0	10.4	10.2
SUBBASIN M04A	23.7	315	10.0	11.2	10.6
SUBBASIN M05	25.1	322	10.0	10.9	10.4
SUBBASIN M08	29.7	331	10.0	10.4	10.2
SUBBASIN M09	31.6	335	10.0	10.2	10.1
SUBBASIN M10	27.2	322	10.0	10.9	10.4
SUBBASIN M11	28.4	327	10.0	10.6	10.3
SUBBASIN M12	17.3	259	14.3	14.9	14.6
SUBBASIN M13	12.8	181	19.3	22.0	20.6
SUBBASIN M14	16.7	270	14.9	14.1	14.5
SUBBASIN M15	21.1	301	11.2	12.1	11.6
SUBBASIN M16	21.0	299	11.2	12.2	11.7
SUBBASIN M17	20.7	301	11.4	12.1	11.8
SUBBASIN M23	1.4	79	41.1	36.6	38.9
SUBBASIN M23A	11.8	267	20.6	14.3	17.5
SUBBASIN M23B	27.9	330	10.0	10.4	10.2
SUBBASIN M24	25.3	307	10.0	11.7	10.9
SUBBASIN MC02	18.6	304	13.2	11.9	12.5
SUBBASIN MC03	22.6	309	10.1	11.6	10.9
SUBBASIN MC04	21.5	303	10.9	12.0	11.4
SUBBASIN MC05	20.9	297	11.3	12.3	11.8
SUBBASIN M18	18.7	19	18.0	18.1	18.0
SUBBASIN M19	18.2	18	17.4	17.5	17.4
SUBBASIN M20	21.0	23	21.0	22.0	21.5
SUBBASIN M21	11.1	7	10.0	11.0	10.5
SUBBASIN M21A	14.1	10	12.2	12.5	12.3
SUBBASIN M22	17.5	17	16.5	16.6	16.6

Table A-2, Hydrologic Statistics and B-IBI Estimates from Horner (2014) Regression Equation (Upper 90% Confidence Bound)

Subbasin	High Pulse Count (HPC) (Average No High Pulses/Year)	High Pulse Range (HPR) Average High Pulse Range/Year (days)	B-IBI Regression Results (Upper 90% Confidence Bound)		
			Regression with HPC	Regression with HPR	Average B-IBI
SUBBASIN M01	23.8	310	17.7	20.4	19.1
SUBBASIN M02	24.2	312	17.4	20.3	18.8
SUBBASIN M02A	18.5	278	22.8	23.2	23.0
SUBBASIN M03	24.5	312	17.1	20.3	18.7
SUBBASIN M03A	25.9	326	16.0	19.2	17.6
SUBBASIN M04	28.0	331	14.5	18.8	16.7
SUBBASIN M04A	23.7	315	17.8	20.0	18.9
SUBBASIN M05	25.1	322	16.6	19.5	18.0
SUBBASIN M08	29.7	331	13.4	18.8	16.1
SUBBASIN M09	31.6	335	12.2	18.5	15.3
SUBBASIN M10	27.2	322	15.1	19.5	17.3
SUBBASIN M11	28.4	327	14.2	19.1	16.6
SUBBASIN M12	17.3	259	24.1	25.1	24.6
SUBBASIN M13	12.8	181	30.0	34.2	32.1
SUBBASIN M14	16.7	270	24.9	24.0	24.4
SUBBASIN M15	21.1	301	20.2	21.2	20.7
SUBBASIN M16	21.0	299	20.2	21.4	20.8
SUBBASIN M17	20.7	301	20.5	21.2	20.9
SUBBASIN M23	1.4	79	50.0	50.0	50.0
SUBBASIN M23A	11.8	267	31.5	24.2	27.9
SUBBASIN M23B	27.9	330	14.6	18.8	16.7
SUBBASIN M24	25.3	307	16.5	20.7	18.6
SUBBASIN MC02	18.6	304	22.8	20.9	21.8
SUBBASIN MC03	22.6	309	18.8	20.5	19.6
SUBBASIN MC04	21.5	303	19.8	21.0	20.4
SUBBASIN MC05	20.9	297	20.4	21.5	20.9
SUBBASIN M18	18.7	19	28.5	29.2	28.9
SUBBASIN M19	18.2	18	27.8	28.5	28.1
SUBBASIN M20	21.0	23	31.9	34.2	33.0
SUBBASIN M21	11.1	7	16.9	19.6	18.3
SUBBASIN M21A	14.1	10	21.5	21.7	21.6
SUBBASIN M22	17.5	17	26.8	27.3	27.1

APPENDIX B – LID AND DETENTION FACILITY DESIGN DATA

Design Parameters for representative stormwater LID and detention facilities used to quantify the retrofit need for the Miller and Walker Creek Watersheds are summarized in the table below. Facilities were designed for representative 1-acre sites with MGSFlood. LID consisted of a bioretention facility upstream of a detention pond in areas with geology of glacial till and a combined LID/infiltration pond in areas underlain by glacial outwash.

Stormwater Design Parameters (1-acre Representative Sites)

Target Condition	Developed Condition	Design Standard Bioretention	Design Standard Detention
Till 100% Forest	Commercial, 90% Impervious, 10% Grass	8% 2-year to ½ 2-yr	½ 2-yr to 50 yr
Till 100% Forest	Multi-Family, 60% Impervious, 40% Grass	8% 2-year to ½ 2-yr	½ 2-yr to 50 yr
Till 100% Forest	Single Family, 35% Impervious, 65% Grass	8% 2-year to ½ 2-yr	½ 2-yr to 50 yr
Outwash 100% Forest	Commercial, 90% Impervious, 10% Grass	--	Infiltrate 8% 2-yr to 50-year
Outwash 100% Forest	Multi-Family, 60% Impervious, 40% Grass	--	Infiltrate 8% 2-yr to 50-year
Outwash 100% Forest	Single Family, 35% Impervious, 65% Grass	--	Infiltrate 8% 2-yr to 50-year

Detention/Infiltration Ponds

Side Slopes:	3H:1V
Depth to riser crest:	3 Feet
Till Infiltration Rate:	0 in/hr
Outwash Infiltration Rate:	3 in/hr

Bioretention Facilities

Side Slopes:	3H:1V
Maximum Ponding Depth	1 foot
Till Infiltration Rate	0.2 in/hr
Outwash Infiltration Rate	3 in/hr
Bioretention Soil Depth	1 foot
Biosoil Porosity	30%
Biosoil Infiltration Rate	6 in/hr

APPENDIX C – Estimate of Total Retrofit Facility Area (Footprint) by Subbasin

Cumulative Surface Area of Required Retrofit Facilities by Subbasin (acres)					
Subbasin	**Till Detention Areas**	**Till Bioretention Areas**	**Outwash Detention/Infiltration Areas**	**Outwash Bioretention Areas**	**Total Retrofit Area**
M01	16.27	7.82	3.98	1.34	28.07
M02	8.03	4.17	2.10	0.68	14.30
M02A	1.77	0.91	1.29	0.44	3.97
M03	6.96	3.62	4.36	1.42	14.93
M03A	2.64	1.38	0.02	0.01	4.04
M04	8.41	4.35	3.69	1.24	16.45
M04A	4.77	2.16	3.25	1.06	10.18
M05	3.79	1.47	1.43	0.46	6.69
M06	2.01	1.00	0.64	0.21	3.64
M08	0.00	0.00	1.68	0.51	1.69
M09	1.51	0.78	2.18	0.69	4.48
M10	2.62	1.33	7.22	2.22	11.18
M11	18.81	7.90	13.09	3.67	39.80
M12	15.40	6.85	3.89	1.21	26.14
M13	16.94	8.62	0.00	0.00	25.56
M14	13.74	7.03	0.01	0.00	20.79
M15	6.89	3.47	2.53	0.84	12.89
M16	1.45	0.76	2.79	0.91	5.00
M17	5.14	2.59	1.35	0.45	9.08
M18	0.09	0.05	2.32	0.80	2.46
M19	6.07	3.01	5.48	1.82	14.55
M20	3.71	1.73	3.52	1.07	8.97
M21	0.21	0.11	2.70	0.84	3.01
M21A	8.23	4.16	5.23	1.73	17.62
M22	1.60	0.77	0.19	0.06	2.56
M23	8.66	4.29	1.66	0.56	14.61
M23A	4.28	1.99	1.37	0.41	7.64
M23B	4.44	2.22	0.43	0.15	7.10
M24	19.39	9.10	3.40	1.07	31.89
MC01N	0.41	0.16	0.37	0.11	0.94
MC02	0.14	0.07	0.74	0.24	0.95
MC03	0.00	0.00	0.37	0.12	0.37
MC04	0.11	0.05	0.82	0.28	0.98
MC05	1.12	0.59	0.89	0.30	2.60
MC06	0.05	0.03	0.32	0.11	0.41
MC07	0.73	0.39	0.80	0.28	1.92
MC08	0.69	0.36	0.25	0.09	1.29
MC09	0.03	0.01	0.14	0.04	0.18

APPENDIX D – Estimate of Total Retrofit Facility Volume by Subbasin

Cumulative Storage Volume of Required Retrofit Facilities by Subbasin (acre-feet)					
Subbasin	**Till Detention Volume**	**Till Bioretention Volume**	**Outwash Detention/Infiltration Volume**	**Outwash Bioretention Volume**	**Total Retrofit Volume**
M01	30.87	12.90	4.20	1.85	49.82
M02	15.03	6.84	2.36	0.97	25.20
M02A	3.31	1.50	1.35	0.60	6.76
M03	13.02	5.93	4.89	2.02	25.86
M03A	4.93	2.26	0.02	0.01	7.22
M04	15.74	7.14	3.88	1.72	28.49
M04A	9.12	3.58	3.62	1.51	17.83
M05	7.43	2.46	1.61	0.66	12.16
M06	3.80	1.64	0.68	0.30	6.42
M08	0.00	0.00	2.11	0.77	2.89
M09	2.83	1.28	2.53	1.01	7.65
M10	4.93	2.19	8.80	3.32	19.24
M11	36.43	13.15	17.96	5.94	73.48
M12	29.57	11.35	4.70	1.79	47.41
M13	31.82	14.16	0.00	0.00	45.98
M14	25.79	11.55	0.01	0.01	37.35
M15	12.96	5.70	2.73	1.18	22.57
M16	2.71	1.24	3.13	1.29	8.38
M17	9.67	4.26	1.44	0.63	15.99
M18	0.16	0.08	2.35	1.09	3.68
M19	11.45	4.95	5.91	2.55	24.86
M20	7.08	2.86	4.38	1.62	15.93
M21	0.39	0.18	3.22	1.24	5.02
M21A	15.47	6.84	5.68	2.43	30.43
M22	3.02	1.27	0.20	0.09	4.59
M23	16.35	7.06	1.77	0.77	25.95
M23A	8.16	3.30	1.71	0.63	13.79
M23B	8.38	3.65	0.45	0.20	12.68
M24	36.92	15.03	4.02	1.56	57.54
MC01N	0.81	0.26	0.45	0.17	1.69
MC02	0.26	0.11	0.85	0.34	1.57
MC03	0.00	0.00	0.40	0.17	0.57
MC04	0.20	0.08	0.86	0.38	1.53
MC05	2.10	0.97	0.91	0.41	4.40
MC06	0.10	0.05	0.33	0.15	0.63
MC07	1.37	0.63	0.81	0.38	3.19
MC08	1.29	0.58	0.26	0.12	2.24
MC09	0.06	0.02	0.18	0.06	0.33

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